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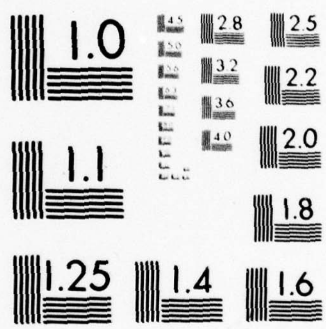
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HYDROCON ACOUSTIC IMAGING SYSTEM

APPENDIX I

THE LITTON HYDROCON SYSTEM

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1 November 1964 to 1 March 1965

APPENDIX I

THE LITTON HYDROCON SYSTEM

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27 April 1965

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I. INTRODUCTION

The Litton system of ultrasonic imaging and sensing using the HYDROCON transducer camera represents what we believe will be a great advancement in the state-of-the-art of underwater vision and detection. One of the key features of this system is the use of a planar array of ultrasonic pickup elements which are individually connected to solid-state amplifier detector and signal processing units. This array converts a focused acoustical image into an array of electrical signals corresponding element-for-element with the ultrasonic focused image. The outputs of these individual elements are then fed to an image converter tube which converts these dc electrical signals into a television output signal by means of a beam scanning tube which is similar to the image orthicon.

Thus by illuminating objects with ultrasonic radiation and focusing the returning signals into an image which is detected by the piezoelectric mosaic and converted by an image converter tube into a television signal, one can "see" with sound in much the same way one can see with optical light waves. The combination piezoelectric and amplifier array, together with the image converter tube, is called the Litton HYDROCON transducer camera.

This type of vision will have important applications whenever the conventional sonar and optical techniques fail. One such important application is in "seeing" over great distances under water. Because of underwater turbidity one can typically see only about 100 feet, unless unusually clear conditions exist. Unusual turbidity will reduce this visibility to almost nothing. The use of microwaves under water presents an even greater problem of attenuation than light waves.

Ultrasonic waves, however, can travel relatively long distances in water without appreciable attenuation. It is a well-known and established principle that sound waves can be focused

and imaged and used like light in the attempt to "see". Several other previous programs have established the feasibility of this principle, but as yet no practical system of this type has been developed.

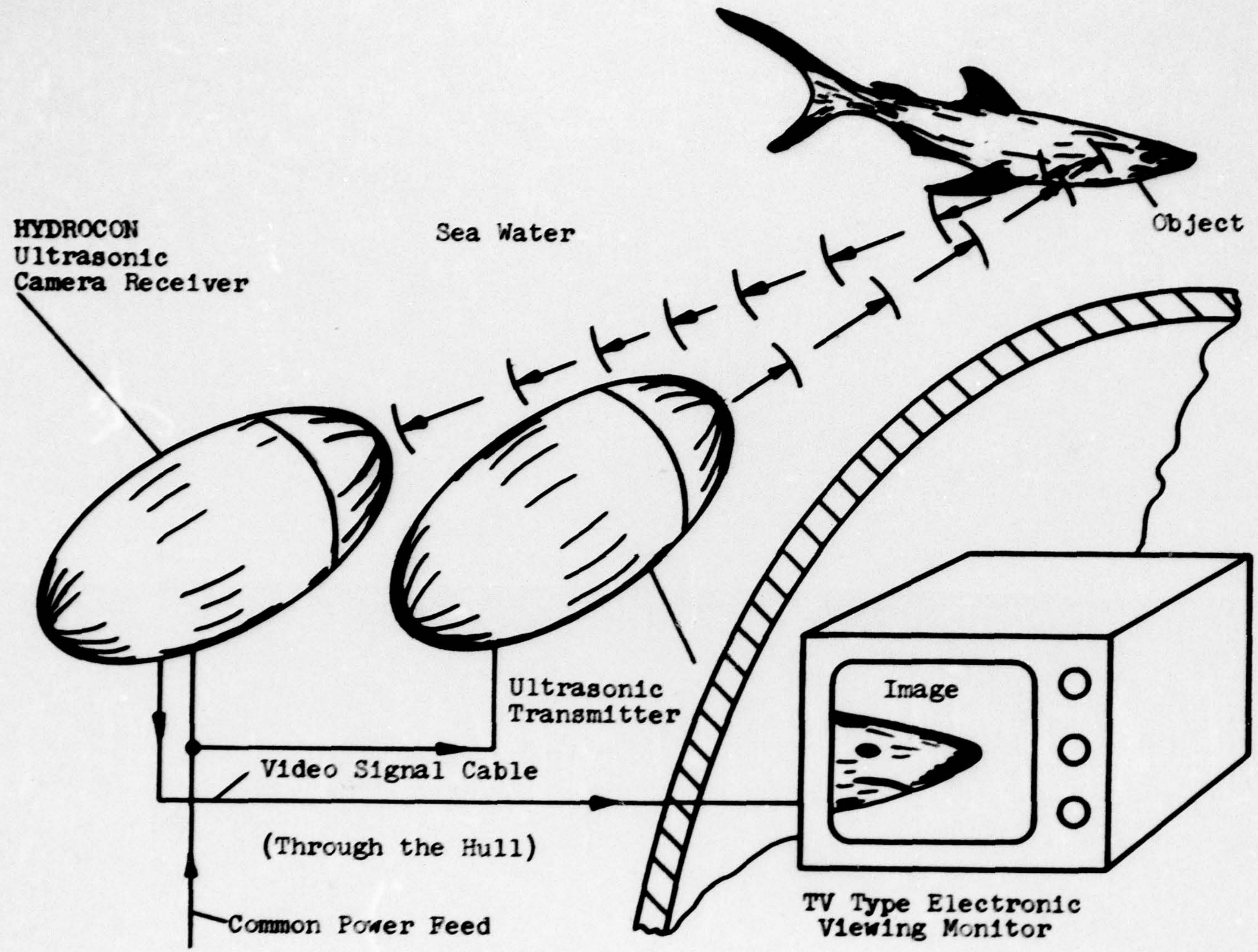
Because of the tremendous future potential of ultrasonic imaging under water for defense applications (and later, perhaps in commercial applications) and because of our new approach which we feel will make this type of system practical, Litton has initiated the HYDROCON program.

II. ULTRASONIC IMAGERY AND IMAGE CONVERSION

The basic ultrasonic imagery concept consists of a transmitter which illuminates the objective field of view and a receiver unit which focuses the reflected waves into an image and converts this ultrasonic image into an electrical signal, which is then converted into a visual display (see Fig. 1).

The transmitter consists of a sound transducer which is typically an array of piezoelectric crystals driven in phase so as to give some directivity to the transmitted ultrasonic signal. The sound waves emerging from the transmitter are roughly focused into an acoustical beam which is wide enough to illuminate the entire field of view simultaneously. Reflected signals from objects within this field of view are received by a lens system and are focused into an ultrasonic image. This ultrasonic image is then converted into an electrical signal which can be displayed typically either by an array of mechanically scanning elements or by a large flat, thin piezoelectric slab which is scanned on its back side by an electron beam. It is in this part of the system that Litton has made substantial original improvements with resulting upgrading of system performance capability. Before describing the Litton HYDROCON approach in detail, it will be helpful to discuss the earlier approaches.

The conversion of the ultrasonic image to electrical signals is one of the key processes in any ultrasonic image system. (See bibliography of Interim Engineering Progress Report No. 1 for published references.) The Sokolov tube is a cathode ray tube with a thin flat piezoelectric crystal in place of the conventional phosphor screen. The size of this piezoelectric crystal is determined by the size of the ultrasonic



SCHEMATIC ARRANGEMENT SHOWING THE RELATION OF THE PRINCIPAL PARTS OF SIMPLE FORM OF ULTRASONIC ILLUMINATION AND VIEWING SYSTEM

Fig. 1

image which must be detected, since the two must be essentially identical. The thickness of the piezoelectric crystal is determined by the ultrasonic frequency and its relation to the degree of resolution required. When the diameter of the crystal is large compared with its thickness and when the thickness is small in comparison with the wavelength of the ultrasonic image, the crystal does not vibrate as a unit. Whenever this thin crystal is placed in the plane of an ultrasonically focused image, various portions of the crystal vibrate with varying amplitudes in proportion to the local signal strength within the image. The vacuum side of the crystal is scanned with an electron beam. The proportion of the electrons returned along the incident electron beam path varies in accordance with the localized intensity of the ultrasonic power density impinging on its outer face. The localized electric fields on the interface of the crystal modulate the percentage of returned electrons, and these returning electrons act as an electrical signal which can be amplified and fed into a display unit. It should be emphasized that the electric field from the piezoelectric crystal which modulates this beam is of an alternating type (not dc) at a frequency equal to that of the ultrasonic signal. Therefore the rate at which the electric beam can be swept is limited by the ultrasonic frequency, since the electron beam must dwell on one element long enough to receive a reasonable number of the acoustical signal cycles. Unless the acoustical frequency is very high, this greatly restricts the rate at which scanning can occur.

In order to increase the sensitivity of this type of image converter, Jacobs et al. added an electron multiplier which amplifies the strength of the returning electron beam. This is operated in much the same way as an image orthicon, with signal gains of 5 to 6 orders of magnitude typically possible.

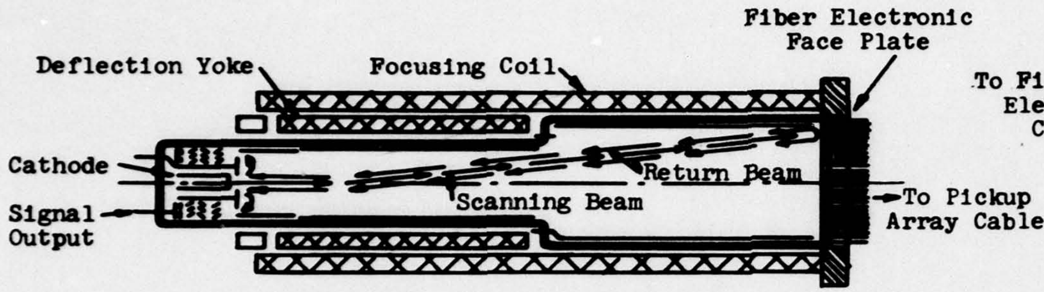
One of the basic problems of this very simple and elementary ultrasonic image detector scheme is that the size of the image to be detected is severely limited by the size of the piezoelectric crystal. As the crystal size is increased in order to increase resolution, a serious problem of tube fabrication arises in that the self-supporting crystal cannot withstand the atmospheric pressure. Furthermore, if the device is to be used under water, there is the additional problem of the hydrostatic pressure. A high resolution capability dictates the use of a very thin crystal, which is very incompatible with resistance to pressure. A high resolution capability dictates the use of a very thin crystal, which is very incompatible with resistance to pressure. The thicker crystal also reduces the resolution possible, since the heavy mass tends to smooth out the ultrasonic image. Furthermore, the electrical potential presented on the inside surface of the crystal is of an alternating type, so that its effect on changing the secondary emission ratio is small as compared with a dc potential profile. This single crystal device does not permit the gating of transducer sensitivity by electrical means.

To overcome many of these problems, personnel from the University of Washington Applied Physics Laboratory (APL) have developed an image conversion device which consists of a linear array of individual piezoelectric sensing units, each of which is connected to an rf rectifying detector unit. The output of these units is connected to a display system which operates in synchronism with the mechanical sweep unit. Results of this device are very good from the standpoint of producing good ultrasonic images of objects under water. One of the chief limitations of this mechanical system is the slow speed of response of the imaging technique.

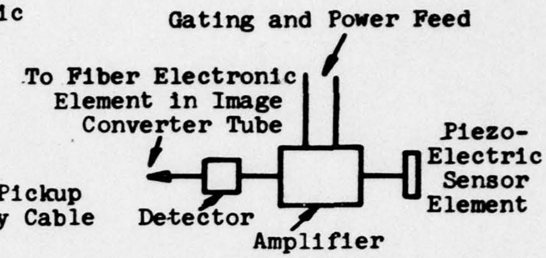
All other previously conceived and developed underwater vision systems of which we are aware have used either mechanical scanning systems like the APL approach or electronic scanning systems like the Sokolov tube. Each system has its advantages, but both are limited for the reasons previously given. We believe that the ultimate method of ultrasonic imaging is to use a large planar mosaic of individual piezoelectric sensors, amplifiers and detectors which continuously monitor the imaged ultrasonic picture and present their outputs to an element of a beam scanning tube. This is the Litton HYDROCON approach and is described in detail in the next section.

III. DETAILED DESCRIPTION OF THE LITTON APPROACH

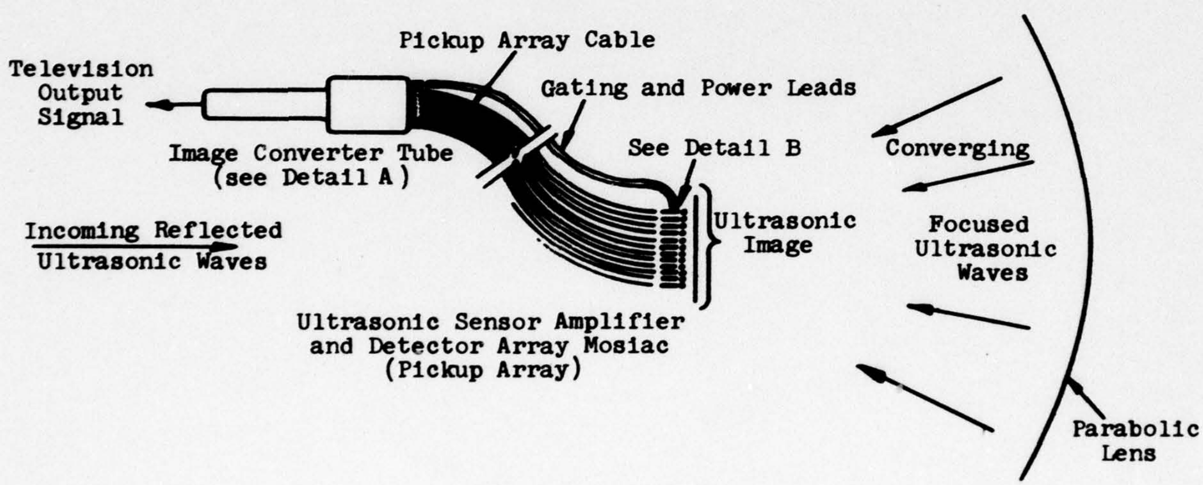
In this approach the image converter system not only incorporates all the desirable features of previous approaches, but also makes use of a number of additional techniques that have truly extended the state-of-the-art. An overall schematic diagram of the Litton HYDROCON system is shown in Fig. 2. One of the most noticeable features is that the piezoelectric image sensor consists of a planar array of individual units. Each one of these elements is individually connected to an rf amplifier and rectifier-detector which not only amplifies and converts the alternating voltage of the sensor to a dc voltage, but also stores this potential for any desired length of time. Signal processing can also be used in these circuits. The dc output from each individual amplifier and rectifier unit is connected to an element of a fiber electronic array which terminates on the inner face of a beam scanning tube. It is therefore clear that the sensor array and the beam scanning surface are physically removed from each other and are connected only by an array of electrical conductors. Therefore, the face of the beam scanning tube can be made as rugged as desired so that it can withstand any amount of atmospheric or hydrostatic pressure. This permits the Litton system to operate at great water depths, with the image converter tube located remotely from the piezoelectric sensor array. Also, this permits the beam scanning tube to be operated individually from the array, which results in many important advantages. Furthermore, the Litton HYDROCON approach permits the sensitivity of each individual amplifier and rectifier chain to be varied independently by varying a dc bias potential. Not only does this permit the adjustment of sensitivity of each element so as to achieve a uniform response across the face of the picture, but it also permits the sensitivity of the entire array to be gated on and off at any desired rate.



Detail A: The Image Converter Tube



Detail B: Typical Element of Pickup Array



HYDROCON ULTRASONIC CAMERA

Fig. 2

The piezoelectric array and detector assembly not only converts the ultrasonic pressure image into an electrical image, but it also amplifies and stores this image over a suitable time period in the fiber electronic faceplate array of the beam scanning tube. It should be emphasized that the response time of the system from the piezoelectric sensor to the ends of the fiber electronic wires is extremely fast, since there is continuous detection of all elements of the picture. The chief response time limitation comes into the system because of the electronic beam scanning and television viewing circuitry. However, this response time is extremely short as compared with the time response of previous ultrasonic viewing systems which depend upon mechanical scan or photographic techniques.

Another important feature of the Litton HYDROCON system is that the transmitted signal is pulsed, as is the sensitivity of the sensor array, in synchronous fashion in such a way that the receiver detects reflected signals during the silent period of the transmitter. Not only does this technique decouple the transmitted signal from the receiver because of direct transmission of ultrasonic power, but it also eliminates the reception of undesired signals due to reverberation, and permits effective quantitative ranging measurements of the objects viewed. This ability to gate the sensitivity of the individual detectors on and off is the key to the ability to use the ultrasonic system in the pulse mode. The HYDROCON system therefore combines the two features of vision and radar ranging by combining the presentation of an entire instantaneous, panoramic picture with accurate range information.

The operation of the beam scanning tube and secondary emission multiplier amplifiers is related to that of the standard image orthicon used in most television camera systems. This part of the tube is illustrated on the left hand side of Detail A of Fig. 2.

The output of the beam scanning tube and secondary emission amplifier may be further amplified and carried by wire cable or electronic link to any desired remote location for viewing or storage, as desired. Since this portion of the equipment is compatible with standard television equipment, there will be no substantial amound of development required for this part of the system.

IV. SUMMARY OF ADVANTAGES OF THE LITTON HYDROCON ULTRASONIC IMAGE VIEWING SYSTEM

The Litton Industries HYDROCON ultrasonic image viewing system will advance the state-of-the-art in the following areas:

1. By separating the piezoelectric scanning array and image converter tube, the system can be built for withstanding very high hydrostatic pressures and "real time" viewing.

2. By rectifying the output of each piezoelectric element and storing this electrical information for any desired period of time, a very sensitive and highly flexible system can be built. For example, this approach permits the pulsing of the receiver sensitivity, which can give range data, eliminate unwanted reverberation signals, and provide a high degree of isolation between transmitter and receiver.

3. By using continuous detection, a very high degree of sensitivity can be achieved, since the picture information can be stored between the electronic beam scanning periods. Autocorrelation techniques can also be readily used with the Litton approach, which can improve the basic signal-to-noise ratio.

4. By using individual elements and the piezoelectric array, a higher degree of resolution is achieved than is possible with a solid element detector, because of the mechanical decoupling of one portion of the ultrasonic pressure image from another.

5. By using all-electronic scan, the image conversion equipment is much lighter in weight than a mechanical scan system.

6. The fact that the detector array can be located remotely from the beam scanning tube provides a high degree of flexibility and mobility of the system. It also permits easy replacement of the image converter tube.

The use of the conversion of the ultrasonic image information into a television signal makes it easy to apply data processing techniques at this stage of the image conversion process.